20th Int. Symp. "Nanostructures: Physics and Technology"
Nizhny Novgorod, Russia, June 24–30, 2012

Current transport in nanocrystalline CdS/InP heterojunction p-n diodes

Zs. J. Horváth[1,2], V. Rakovics[2], Yu. A. Yakovlev[3] and *P. Turmezei*[1]

[1] Óbuda University, Kandó Kálmán Faculty of Electrical Engineering,
Institute of Microelectronics and Technology, Budapest, Hungary
[2] Hungarian Academy of Sciences, Research Centre for Natural Sciences,
Institute for Technical Physics and Materials Science, Budapest, Hungary
[3] Ioffe Physical-Technical Institute, St Petersburg, Russia

Abstract. Current-voltage behaviour of CdS/InP heterojunction p-n diodes were studied in the temperature range of 80–320 K. The diodes were prepared by chemical bath deposition of n-type nanocrystalline CdS layers on p-type InP substrates. It is shown that the current through the junctions is dominated by electron transport. The actual current mechanisms are the thermionic-field emission for forward, and the field emission for reverse direction.

Introduction

CdS thin films are studied mainly for photodetector and solar cell purposes. The chemical bath technique (CBD) is a relatively simple and inexpensive method to prepare homogenous nanocrystalline films with controlled composition. In particular, CBD is widely used for achieving good-quality CdS films [1,2]. Extensive research has been done on the deposition and characterization of CdS semiconductor thin films due to their potential applications in the area of electronic device fabrication as well [3,4].

In this work the electrical behaviour of CdS/InP heterojunction p-n diodes have been studied. The diodes were prepared by chemical bath deposition of n-type nanocrystalline CdS layers on p-type InP substrates. The current through the junctions was dominated by electron transport. The actual current mechanisms were the thermionic-field emission (TFE) for forward, and the field emission (FE) for reverse direction.

1. Experimental

The substrates were p$^+$ (001) oriented InP wafers with a free hole concentration of about 3×10^{18} cm^{-3}. First a p-type InP layer was grown with a concentration of about 1×10^{17} cm^{-3}

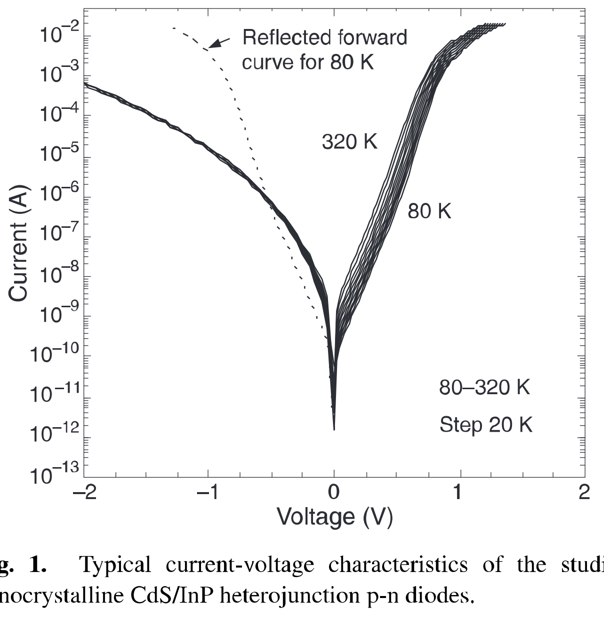

Fig. 1. Typical current-voltage characteristics of the studied nanocrystalline CdS/InP heterojunction p-n diodes.

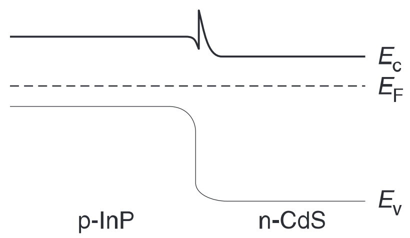

Fig. 2. The band structure of InP/CdS heterojunction [9].

and a thickness of about 1.5 μm by liquid phase epitaxy. The CdS thin films were deposited by using the CBD technique. Baths containing $CdSO_4$ (1 mM/l), thiourea (5 mM/l), and NH_3 (1.7 mM/l) have been used. The slides were kept vertically in the beaker. The temperature of deposition process was 65 °C, and the duration of deposition was 30 minutes. The bath solution was stirred during the deposition.

After the deposition, the CdS films were washed with water ultrasonically to remove the loosely adhered CdS particles on the film, and finally dried in air. According to scanning and transmission electron microscope measurements, the CdS films were nanocrystalline with crystal size of 10–20 nm and total thickness of about 60 nm [5]. The optical band gap of the layer was 2.42 eV, as obtained by transmission measurements performed in the wavelength range of 400–1000 nm [5]. (This is the usual value published for CdS band gap [6].)

The diodes were fabricated by evaporation of gold-zinc and gold-tin contacts to the InP and CdS, respectively. The area of gold-tin contacts to CdS was 2.87×10^{-8} m^2, but as no mesa etch was performed, the effective area of the diodes can be larger. The diodes were studied by current-voltage (I-V) measurements in the temperature range of 80–320 K in dark.

2. Results and discussion

The typical I-V characteristics of the diodes are presented in Fig. 1, as a function of temperature. The lack of temperature dependence and the shape of reverse current indicate that it is dominated by field emission [7], while the exponential dependence of forward current on the bias and its weak temperature dependence indicate that it is dominated by thermionic field emission (TFE) through a low potential barrier [8]. An interesting behaviour of these junctions is that due to the different current mechanisms for forward and reverse branches, the re-

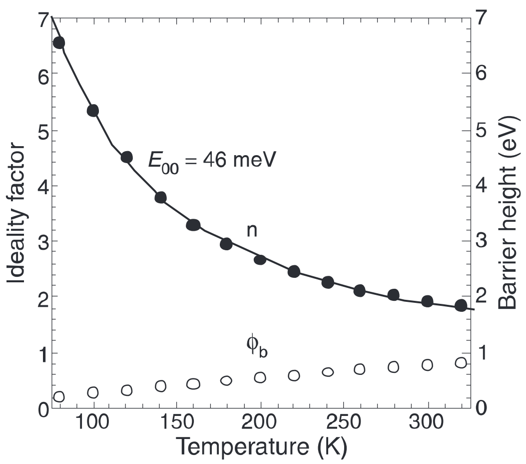

Fig. 3. Experimental temperature dependences (dots) of ideality factor and apparent barrier height evaluated for thermionic emission. Solid line is theoretical dependence of ideality factor for thermionic-field emission with characteristic energy of 46 meV.

verse current is higher at low biases and low temperatures, than the forward current, as it can be seen in Fig. 1.

Riad and co-workers calculated the band offsets of the InP/CdS heterojunction and proposed a band diagram presented in Fig. 2 [9]. They obtained the band offsets of conduction and valence band edges, as 0.09 and 0.77 eV, respectively. Due to band banding, the potential barrier for electrons is a few tens of meV, while that for holes is about 0.8 eV. So, the hole transport is blocked by the high potential barrier, and the current through the junction is dominated by electron transport, for forward direction by TFE, for reverse direction by TE.

The ideality factor and apparent barrier height evaluated for thermionic emission from the forward currents are presented in Fig. 4. Similar temperature dependences of these parameters are obtained for Schottky junctions, if the dominating current mechanism is the TFE [8]. In Fig. 3 solid line shows the theoretical temperature dependence of ideality factor for TFE fitted to the experimental points with characteristic energy E_{00} of 46 meV [8]. The excellent agreement between the experiment and theory clearly indicates the validity of the above explanation.

3. Summary

Nanocrystalline CdS/InP heterojunction p-n diodes have been prepared by chemical bath deposition of CdS. It has been shown that the current through the junctions is dominated by electron transport. The actual current mechanisms are the thermionic-field emission for forward, and the field emission for reverse direction.

References

[1] L. Pintilie, E. Pentia, I. Pintilie, and D. Petre, *Mat. Sci. Eng. B* **44**, 403 (1997).
[2] L. Pintilie, E. Pentia, I. Pintilie, T. Botila, and C. Constantin, *Appl. Phys. Lett.* **76**, 1890 (2000).
[3] S. Bhushan, M. Mukherjee, and P. Bose, *Radiat. Eff. Defects Solids* **153**, 367 (2001).
[4] M. Mukherjee, P. Bose, and S. Bhushan, *Ind. J. Pure Appl. Phys.* **39**, 804 (2001).
[5] V. Rakovics, Zs. J. Horváth, Z. E. Horváth, I. Bársony, C. Frigeri, T. Besagni, *Phys. Stat. Sol. (C)*, **4**, 1490 (2007).
[6] A. Yoshikawa, Y. S. Sakai, *Solid-State Electron.* **20**, 133 (1977).
[7] F. A. Padovani , R. Stratton, *Solid-State Electron.* **9**, 695 (1966).
[8] Zs. J. Horváth, *Solid-State Electron.* **39**, 176, (1996), and references therein.
[9] A. S. Riad, S Darwish, H. H. Afify, *Thin Solid Films* **391**, 109 (2001).